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HARMONICS

BY

C. Egerton Lowe

PROGRESSIVE STUDIES

FOR THE PIANOFORTE

EDITED, ARRANGED IN GROUPS, AND THE FINGERING REVISED AND SUPPLEMENTED

BY

FRANK [illegible]OR.

THIS Collect[illegible] to [illegible]ate the various elements of a [illegible]*ique*, and to provide student[illegible] overcoming the different sp[illegible]ountered. With this view, [illegible] those in each group [illegible]aving reference to sor[illegible] part of the Studies th[illegible] standard works of the r[illegible] these are included numer[illegible]eat practical utility, have hit[illegible]

1. FIVE-FINGER [illegible] .. .. Part 1
2. „ [illegible] .. .. „ 2
3. SCALES .. [illegible] .. .. „ 3
4. „ .. [illegible] .. .. Part 1
5. BROKEN CHO[illegible] .. .. „ 2
6. „ [illegible] .. .. „ 3
7. „ [illegible] .. .. „ 4
8. „ [illegible] .. Part 1
9. „ [illegible] .. „ 2
10. LEFT HAND [illegible] .. Part 1
11. „ „ [illegible] .. „ 2
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14. ARPEGGIO [illegible]IO. .. Part 1
15. „ [illegible]TION AN[illegible]MOLO „ 2
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17. VELOCITY [illegible] 43. PART I[illegible] .. Part 1
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19. „ [illegible] 45. ORNA[illegible] .. Part 1
20. „ „ 4 46. [illegible] .. „ 2
21. „ „ 5
22. „ „ 6 47. AC[illegible]MELODY.. Part 1
23. „ [illegible] .. „ 2
24. FIGURES IN S[illegible]ENCE [illegible]PS .. Part 1
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26. BROKEN THIRDS, SIXTH, AND OCTAVES .. .. Part 1 51. RHYTHM .. .. Part 1
27 BROKEN THIRDS, SIXTHS, AND OCTAVES .. .. Part 2 52. „ .. .. „ 2

53. EXERCISES FOR THE WEAKER FINGERS. By J. A. O'NEILL.

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PROGRESSIVE STUDIES for the PIANOFORTE.

BOOK 53.

EDITED BY FRANKLIN TAYLOR.

EXERCISES

FOR THE

WEAKER FINGERS

BY

J A O'NEILL.

REFACE.

IT is an ackn[illegible] that the chief obstacles to good execution and equality of t[illegible]h the weakness of the fourth and fifth fingers, and in a want of [illegible]e passing the fourth finger over the thumb.

To overcome the [illegible]culties the following Exercises have been specially des[illegible] object is to place the weak fingers on a perfect equa[illegible] [illegible]hers, thus entirely avoiding the defect of the general m[illegible]ercises, which, by allotting as much (or more) work to the n[illegible]y [illegible] as to the naturally weak fingers, leave the *relative* ineq[illegible]al[illegible] st[illegible]ength and skill unaltered.

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LESSONS IN HARMONICS

FOR VIOLINISTS

AND OTHER MUSICAL STUDENTS

WITH NOTES ON SOUND AND RESULTANTS

ELEMENTARY EXPLANATIONS AND EXPERIMENTS

BY

C. EGERTON LOWE.

PRICE ONE SHILLING.

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The author wishes to express his indebtedness to the following works on Sound and Acoustics:—

"Sound." A. Gardiner. (Science Manuals.)

"Elementary Text-book on Sound." J. Don. (University Tutorial Series.)

"Text-book on Sound." E. Catchpool. (University Tutorial Series.)

"The Scientific Basis of Music." W. H. Stone. (Novello and Co.)

"Sound and Music." Sedley Taylor. (Macmillan.)

"On Sound." John Tyndall. (Longmans.)

"Sound." C. L. Barnes. (Science Manuals.)

"Sensations of Tone." Helmholtz. (Longmans.)

Etc., etc.

PREFACE.

ALTHOUGH there exist many and varied books dealing with Sound in its different aspects, there are none, so far as the author of the present little work is aware, specially devoted to the subject of Harmonics treated experimentally in a simple and elementary form.

Of all matters connected with music, perhaps one of the most interesting and fascinating is the wonderful power and influence exercised by harmonics in determining what is known as the *tone-colour* (*klangfarbe*) of various instruments and sounds. Students and others who think of harmonics only as peculiar effects produced by players upon stringed instruments, and who have made no attempt to analyse the constituent parts of so-called *single sounds* (which are compound sounds), can hardly form an idea of the marvellous variety which exists in tone-colour.

In studying the following chapters the experiments described should be made in the order in which they are given. Students who do not play the violin may have to omit the Violin Experiments, but nevertheless they should read the entire work in order to understand the subject clearly.

The author's very grateful thanks are due to his friend Dr. W. G. McNaught for his valuable suggestions and never-failing help and assistance.

C. E. L.

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LESSONS IN HARMONICS AND RESULTANTS.

ELEMENTARY EXPLANATIONS & EXPERIMENTS FOR VIOLIN & OTHER MUSICAL STUDENTS.

CHAPTER I.—SOUND AND VIBRATION.

1. The laws which govern the production of Harmonics and Resultants are necessarily part of the general laws of Sound or Acoustics. It will therefore be advisable to state a few simple facts about sound in general before approaching the particular object of this elementary treatise.

Cause of Sound.

2. Sound is produced by concussion or motion resulting from some form of action or employment of energy, as in striking a gong, plucking or bowing on a string, clapping the hands, dropping a book, etc. The movement of the material or matter agitated causes a vibration, which is conveyed to the air, and produces what are termed WAVE-MOTIONS, OR ATMOSPHERIC VIBRATIONS.

Transference of Vibratory Movement.

3. These wave-motions travel "to-and-fro," or "forward and backward"; that is to say, a pendular movement is set up in the particles of air. The particles first affected communicate their movements to the particles next in their path, and then recede in the *opposite* direction before finally coming to rest in their original position. In this manner vibrations are carried through the air, and eventually the particles outside the ear are reached. Then the wave-motions or vibrations, beating against the membrane or drum of the ear, cause a sensation which is conveyed to the brain, and is called SOUND.

To-and-Fro Movement.

4. A simple example of "to-and-fro" movement can be observed with a row of railway carriages at rest. If the end carriage is given a push, as when coupling-on another carriage, it communicates the impulse to its neighbour, which again delivers the motion to the third carriage, and so on. In this manner the movement is carried along throughout the entire row, each carriage moving *backwards* (through the resiliency of the springs in the buffers) after it has performed its work of *forwarding-on* the original impulse.

Sound-Waves are carried in all Directions.

5. When any form of concussion or action takes place, as, for instance, in the examples given in PAR. 2, a great many of the air particles are affected at the same time. As each particle behaves in the same manner as that described in PAR. 3, the waves of vibration are as a consequence *carried about in all directions* in concentric spheres. As these circles increase in size the vibratory energy of the air particles correspondingly lessens, until at last it ceases altogether. It will help the student to better understand the means by which sound is propagated through the air if he notices the effect of dropping a stone into smooth water. A series of concentric circles is immediately formed, beginning with very small ones, which show great energy in imparting their movements to their neighbours, but always gradually extending in size, although lessening in vigour. Eventually they entirely cease, and the water returns to its former placid condition.

Speaking-Tubes.

6. That it is simple enough to limit or confine the directions in which vibrations first begin to move can be easily proved; as, for example, in the familiar instance of a speaking-tube. When speaking into one end of the tube the atmospheric vibrations caused by the voice are confined in a small compass, and are consequently sent forth with a concentrated force which enables them to be distinctly heard a considerable distance away. *See also* PAR. 28.

Music and Noise.

7. When vibrations follow each other at regular intervals of time and are of sufficient rapidity, they produce sounds which may be termed MUSICAL,[1] inasmuch as they have a definite

[1] All musical sounds have not necessarily a pleasing effect. They may have a definite pitch and yet be very harsh.

pitch corresponding to some note, as C, E♭, F♯, etc. When, however, the vibrations are otherwise than thus described the effect they produce may be termed NOISE.

8. Tyndall remarks that if a pigeon could flap its wings at, say, the rate of a hundred times per second, its flight through the air would be accompanied by a musical sound. Sufficient rapidity for this effect is, indeed, obtained by the humming bird, which, whilst hovering, apparently motionless, over a flower, moves its wings with such remarkable rapidity (too great to be actually seen, the wings appearing in a kind of haze) that a humming musical sound is produced, thereby giving origin to the name of the bird. Another familiar instance may be cited, too, in the singing noise made by a mosquito or a bluebottle, produced, likewise, by a rapid movement of the wings in flying.

The Cultivation of the Ear.

9. All musical students are strongly urged to follow Schumann's advice to cultivate the ear. Find the exact pitch of your bicycle-bell, dinner-gong, the strike of the clock, the notes of the cuckoo, etc.[2] Various musical tones can be excited by tapping glass globes; by lightly pressing a wetted finger round the thin edge of drinking glasses (in this latter case it is possible to obtain a complete octave of notes by varying the quantity of water in each glass); and very shrill sounds can be procured by bowing with a well-resined bow on the edge of a thin glass finger-bowl, etc.

The Unison of Sounds.

10. Whenever two sounds from similar or different sources perfectly agree in pitch, the reason for this agreement is that the vibrations which cause the sounds are *exactly equal in number.* Sounds such as these are said to be in UNISON.[3]

Satisfactory Vibrations.

11. Sounds in general musical use are produced by vibrations ranging from about 28 to 4,160 per second. These extremes correspond to the deepest A and the highest C of a 7¼-octave pianoforte. It is impossible to count these vibrations; but by the aid of a special acoustical instrument called the *Siren*, or *Syren*, the number of vibrations per second of a note of any pitch can be accurately ascertained.

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[2] The writer, for instance, passing through a squeaking swing-gate, found that it squeaked B flat above the treble stave when it was pushed one way, and an octave lower when it swung back again.

[3] See also CHAP. X., PARS. 118, 119.

Unsatisfactory Vibrations.

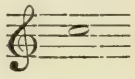
12. Vibrations much *below* 28 per second hardly affect the ear as a musical sound, and when they exceed about 4,160 per second they become difficult, and very soon impossible to distinguish as regards their definite pitch; what are really vibrations of different rates sounding nearly all alike. Consequently, there is no utility in extending the compass of the modern pianoforte of $7\frac{1}{4}$ octaves beyond, perhaps, an extra note or two. Some organs are, however, provided with stops which produce deeper and higher sounds; but these are exclusively used to reinforce the octaves.

Limits of the Pitch-distinguishing Faculty of the Human Ear.

13. When vibrations exceed a certain high limit they altogether cease to be audible. Some ears are more acute than others. One person will hear nothing beyond, say, 10,000 vibrations per second, while another may be able to distinguish as sound, vibrations reaching as high as 28,000, which is about the limit of the human ear. Some animals, cats and dogs for instance, will often start and cry in distress at sounds which are quite inaudible to the human ear.

Variations of Standard Pitches.

14. It is common knowledge, and an embarrassing fact to all concerned with music, that pianofortes are often tuned to different pitches. A few years ago the standard "Concert" or "Philharmonic Pitch" adopted in England had gradually risen until it reached 540 vibrations per second for C in the treble stave:—



Since 1896 the pitch more generally used (at the Queen's Hall, London, etc.) is that known as "Diapason Normal" or "French Pitch." This produces 517 vibrations for the same C as above (a difference of, practically, a semitone), and better agrees with the pitch used in the time of Beethoven (1770–1827). Writers on acoustics often adopt what is termed a "Philosophical Pitch" of 512 vibrations for C in the treble stave. This number can be divided back to an imaginary C of one vibration, and as it is the simplest theoretical standard for making calculations it will be used in the explanations of temperament and resultants given in CHAP. X.

Transmission of Sound.

(*a*) THROUGH AIR.

15. Sound travels (that is to say, vibrations are conveyed) through air, liquids, and solids. They most often reach the ear through the air only; as, for instance, when in a room you hear a sound originating in that same room, or when out of doors you hear carts rattling in the street in which you are walking. But when you are in a room with closed windows and hear, say, a piano-organ playing in the street, the vibrations have to travel first through the air in the street, next through the walls and window of your house, and then through the air of the room you are in before they finally beat against the membrane of your ear and announce themselves as sound.

(*b*) THROUGH LIQUIDS.

16. If a bunch of keys is rattled, or a bell rung, in the midst of a large vessel of water the sound can be perfectly well heard; thus proving that vibrations can be conveyed through water or liquids to the air; furthermore, a person swimming or holding the head under water will distinctly hear a sound, such as a shout, or the ringing of a bell, originating in the air above. In the former cases the sounds[4] travel first through the water and then through the air before they reach the ear; in the latter cases the conditions are just reversed.

(*c*) THROUGH SOLIDS.

17. Various simple means can be employed to prove that sound travels through solid matter; as by pressing one end of an iron, steel, or wooden rod, or a wax candle, etc., against a door, and applying the stem of a vibrating tuning-fork to the other end. The vibrations travel through the *medium* or *conductor* (the agitation or quivering of which can be felt with the fingers) and communicate themselves with great intensity to the wood of the door.[5] An interesting experiment, too, can be made if when taking a country walk you come across the long trunk of a hewn tree. If you press your ear against one end whilst some one taps or scrapes the other end the vibrations will run through the solid mass of wood and be most distinctly heard by you.

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[4] It must be understood that in this respect the expression *sound* is always meant to indicate *vibrations*, or *wave-motions*.

[5] See PAR. 22, on Resonance.

Vibrations in Contact with the Ear.

18. Sounds are always heard with greatly increased force if the ear is pressed against the vibrating body; because in other circumstances, as a rule, much of the energy of the vibration is distributed over a large space of air (thereby considerably weakening the tone) before it reaches the ear. If, for instance, one side of a piece of wood, or of a book, is pressed against the ear and the other side is touched with the stem of a vibrating tuning-fork the sound is so intense as to be scarcely bearable, as a consequence of the full shock of the vibrations beating almost directly against the delicate membrane of the ear.

A Vacuum destroys Vibrations.

19. Vibrations will not travel through a vacuum, for the simple reason that there will be no medium to carry them forward. This is proved by placing, say, a musical box (suspended by silk thread so that it shall not touch any surface which would convey the vibrations to the air outside) in a receiver with an air-pump attached. While there is air in the receiver the sound will be heard from outside; but as soon as the last particle of air has been exhausted the sound utterly ceases.[6] The ether (the subtile medium presumed to occupy all space) which remains in the vacuum will not carry forward these vibrations; but as soon as a minute portion of air is re-admitted into the receiver the sound from the musical box will be very faintly heard again, provided it has not run itself down, and the strength of the tone will continue to increase as more air is admitted.

Degrees of Loudness.

20. Sounds not only vary in pitch but also in loudness and tone-colour.[7] Degrees of loudness are due to the *amplitude*, and not to the rapidity of the vibrations. By amplitude is meant the largeness or width of the swing of a vibration. For instance, if with a bow one plays on the G string of a violin softly and slowly the amplitude of the vibration of the string is very slight,

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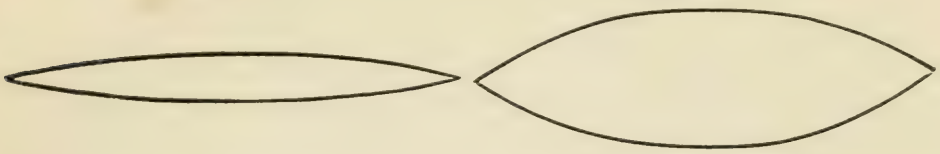
[6] After the air is exhausted the receiver may be filled with hydrogen gas, which is about fourteen times lighter than air. After the gas has been pumped out the most complete vacuum possible (although not an absolute vacuum) is obtained.

[7] Variety of tone-colour is explained later on. *See* CHAP. VIII., PAR. 113(e)

somewhat as at Fig. A; but if the string is played-on with more strength and movement of the bow the amplitude is very considerably increased, as at Fig. B :—

FIG. A. FIG. B.



The smaller and greater amplitudes of the string, as exemplified above, cause a correspondingly smaller and greater amplitude of atmospheric vibrations.

Pendular Law.

21. Another simple example of amplitude can be shown with a piece of string having a small weight attached to one end. Hold the string in the hand, or suspend it from a hook, and swing it forwards and backwards like a pendulum, making larger or smaller amplitudes of movement. Provided the same weight and length of string are maintained, the time occupied in a "to-and-fro" movement will be *exactly the same*, whether the amplitude be large or small.

Resonance.

22. If a string is tightly stretched through the air from two points, or suspended from a hook and tied to a heavy weight, and then plucked or bowed-on it will produce but a very feeble sound. This is because the vibration of the string alone causes, comparatively speaking, a very slight air-disturbance. But if the string is stretched across some material which will *vibrate in sympathy* with it, the larger surface thus agitated will produce a far greater atmospheric wave-movement. The increase of amplitude thus gained is called RESONANCE. For example, a tuning-fork agitated and held in the air gives forth very little sound; but the moment it is placed, say, on a wooden surface the tone is greatly augmented, and especially will it be so if the fork is applied to a small, closed wooden box. If a pen or nail, etc., is placed loose inside the box it will begin to jingle as soon as the vibrating fork is applied to the outside; proving that the vibration is being carried to all parts of the wood.

Resonance in Violins, etc.

23. Violins, etc., are resonant in the same way as described above. As soon as a string is sounded every part of the violin begins to quiver. The bridge conducts the vibrations to the

table, and the little wooden sound-post serves to further conduct them direct to the back. In the pianoforte the strings are stretched across a large surface of wood called the *sounding-board*.

Vibration in Different Woods.

24. Some woods vibrate more readily than others. Thus pine-wood, of which the table of the violin is usually made, is very porous, and vibrates quickly; but maple, of which the back is generally made, is a much denser wood, and consequently vibrates more slowly. It is the combination of the porous and dense woods which helps, with the aid of the sound-post, etc., to produce a good, sonorous, and full tone in a violin.

Sound Conductors.

25. Some mediums are better than others as sound-conductors, and for creating resonance. Thus wood, steel, brass, iron, etc., are excellent, but cork and indiarubber are not good. If a small piece of the latter material is placed on a wooden surface, and the stem of a vibrating tuning-fork pressed on it, the sound is very slightly reinforced as compared to the result obtained when the fork is applied to the wood only.

Sympathetic Vibrations.

26. Mediums such as wood, etc., resonate to a sound of *any pitch*, provided they are placed *in contact* with the vibrating body. For example, the wood of a violin vibrates just as readily and freely to one note played on it as to another. But resonant vibration can only be occasioned *without contact* under certain definite circumstances, of which the following examples will give simple illustrations:—(1.) A particular note (B, G, C, as the case may be) played on a violin causes, say, a suspended bell-shaped gas globe in the room to vibrate, while a note of a different pitch fails to elicit any response from the same object. The reason for this behaviour is that the pitch of the note which caused the globe to vibrate was the same as that of the globe itself; this can be proved by tapping the latter. (2.) While playing on the pianoforte some article in the room begins to jingle. If it is *on* the pianoforte and the jingling is produced by the playing of various notes it will probably be excited through the vibratory movement of the wood of the pianoforte caused by the playing. But if the article is *not in contact* with the pianoforte the reason will be the same as that given above. The wave-motions produced by the violin or pianoforte travel about the room impinging themselves against everything. If they happen to collide with a medium capable of naturally vibrating at *only the same rate* as themselves (that is to say, something that can

only produce a similar pitch), they will set it in motion, in many cases too feebly to be heard or noticed, but sometimes with sufficient strength to produce a definite sound. Further examples of SYMPATHETIC VIBRATION (as this form of resonance is termed) will be given later on. *See* PARS. 55, 56. [8]

Resonance in Air.

27. Columns of air also create resonance. Thus if a small, round cardboard box, or a roll of paper, say, six to twelve inches long, and *open at either end*, has a vibrating tuning-fork applied close to one of the openings, the sound from the fork will be considerably reinforced. When the column of air is *closed at one end*, as in a glass jar, it must be of a particular length, according to the pitch of the fork, for perfect resonance. This is an important feature in organ pipes. [9]

Reflection of Sound.

28. Sound is reflected in the same way as Light. One of the most familiar instances is that of an ECHO. A sound-wave strikes against some opposing surface, and being *reflected* it produces a repetition of the original sound, or an echo. In the case of a speaking-tube (mentioned in PAR. 6) the vibrations are reflected from side to side of the tube as they travel down.

Velocity of Sound.

29. Sound travels at various degrees of speed through different mediums. Its velocity in air of the temperature of 60 degrees *Fahrenheit* is about 1,120 feet per second, and it will be slightly *more or less* according to whether the air is *warmer or colder*. Its velocity in water is about four times greater than the above; in iron about seventeen times greater; and in pine-wood about ten times greater. The reason for these differences is that vibrations pass most quickly through the most elastic substances, and liquids, metals and wood are more elastic (as compared with their respective densities) than air.

30. Fortunately all sounds, be they of any pitch, loudness, or quality, travel at equal rapidity under the same conditions. If this were not so the sounds of an orchestra would be quite chaotic to the listener a little distance away. It should, moreover, be observed that although sounds become *weaker* the farther they travel, they do not lose their *pitch;* the air-vibrations produced by the original cause continue at the same speed until they are ultimately lost in space.

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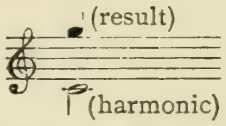
[8] Sometimes sympathetic vibration may be caused by the harmonic (or overtone) of a note.

[9] All musical instruments have some form of mechanism or means for creating resonance.

CHAPTER II.—THE "OCTAVE HARMONIC."

31. Violin students who have reached the stage of playing harmonics, and know perfectly well how to produce them, are often unaware of the cause for the difference in sound between *stopped notes* and *harmonics;* that is to say, between the sounds produced when the fingers are pressed tightly on the strings and those produced when the strings are touched lightly. Authors of violin schools rarely attempt an explanation, generally merely giving the note to be played with the resulting harmonic, thus—



or, at most, stating something to this effect: "If a string is touched lightly at a quarter of its length, a harmonic, two octaves higher than the sound of the full length of the string, is produced," etc.

32. An explanation of the reason for this peculiar behaviour of a string, under the circumstances described, is a matter of considerable detail, and perhaps to this reason, as much as to any other, may be ascribed the pretty general shelving of the subject in ordinary violin teaching.

33. Violin students who follow the explanations to be given, and who carry out the experiments described, will, it is hoped, be rewarded for their trouble by being able to understand some of the more obvious laws governing the production of harmonics, and they will be interested to understand why the correct placing of the bow at different portions of the string between the bridge and fingerboard, according to the note stopped, is of considerable importance to good tone-production (*see* PAR. 102). Pianists and other music students who have not hitherto made a special study of the subject of sound may also find much to interest them.

34. As it is desired to make the matters dealt with intelligible to beginners as well as to more experienced musical students, every point will be explained simply and minutely. No previous knowledge of the particular subject will be assumed.

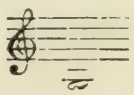
Experiments with the Violin.

35. It will be best if all the violin experiments are made on the G string. Whatever rules apply to this particular string apply equally to any other string, either on a violin, viola, or violoncello, and also, with certain modifications, to the strings of a pianoforte.

EXPERIMENT I.

Get the best silver G string you can (unburnished by preference) and tune it exactly to the G of your pianoforte. With the bow, play the open note in an ordinary way, and watch the string vibrating or oscillating. Draw the bow quickly and with some considerable strength, and you will observe that the oscillation extends very nearly to the D string on one side, and to the edge of the finger-board on the other. This will demonstrate what is meant by the "vibration of a string." You can also feel the vibration, or quivering, of a deep bass pianoforte string by touching it with your fingers, just after it has been struck in the usual way, but before allowing the damper to fall again.

36. The note played on the violin was G below the lines:—



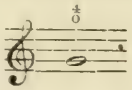
and this, for the future, will be called the *fundamental*, that is the *lowest* or *foundation* note. The first important fact to be learnt concerning a note is that WHENEVER A STRING IS FREELY VIBRATING IT PRODUCES BESIDES, AND AT THE SAME TIME AS ITS FUNDAMENTAL NOTE, A CONSIDERABLE NUMBER OF OTHER SOUNDS, CALLED HARMONICS, PARTIALS, OR OVERTONES. When you have sufficiently trained your ear you will be able to hear at least one or two of these harmonics, as we will decide to call them, quite distinctly, whenever you play, singly and slowly, the lower notes of a pianoforte, or even a violin; but at first it will suffice to accept it as a fact that these extra sounds are, actually, *always in existence*.

37. If you have a full-sized violin you will find the string measures thirteen inches from the bridge to the little ebony nut at the end of the fingerboard. The small portion of string between the tail-piece and the bridge does not affect the sound of the longer portion. This you can prove by pressing a finger on the former whilst you bow in the usual manner on the latter. Therefore, thirteen inches is the whole working portion of the "open" string.

38. When you press your finger *tightly* on a string the lower part, that is the part *behind* your finger, does *not* vibrate. Your finger, by its pressure, has the act of shortening the working part of the string, and, as will be more fully explained as we proceed, the *shorter* the string the *higher* is the sound produced.

Experiment II.

Measure off one-half of the string, that is 6½ *inches from either end, and make a little chalk mark on the fingerboard at the spot. Now place the tip of the finger as lightly as you can on the string at the place you have marked, and, playing with the bow, you will produce what is called the "octave harmonic," that is a note one octave higher than the fundamental—*



Watch the string very carefully in a good light and you will see that BOTH HALVES ARE VIBRATING, *which we have just learned is not the case when the finger is pressed down tightly. Now, whilst bowing very straight and with some speed, quickly lift away the finger and you will notice, that although the two halves are vibrating, a small space at the exact half, where you put the chalk mark and placed your finger, is* NOT VIBRATING, *and is, apparently, still.*

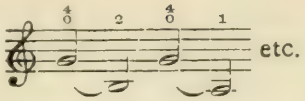
39. Persevere practising the above experiment until you can see the result quite clearly, even with your finger still resting on the string. You can also try it in another way by placing the violin on a table, and, whilst you continue bowing, touching the string in the middle with the feathery part of a quill pen, or even the edge of a coin. When the violin is placed in the position just described you can easily demonstrate that a harmonic can be produced by drawing the bow on *either side* of the place you are touching *without any alteration of sound occurring.*

Segments and Nodes.

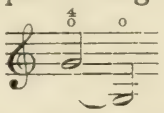
40. Some writers call the light touching of a string to procure a harmonic "*damping* the string," an expression which will be simpler for us also to use for the future. It will be as well also to learn now that the vibrating portions of strings are usually called SEGMENTS (or loops), and the places where the points of rest occur NODES (from *nodus*, the Latin for knot). Thus, when you play the open G the string vibrates as a *whole*—  ; but when you "damp" it in the middle to produce the "octave harmonic" it vibrates in *two segments*, divided by a *node*,  .

41. When you are able to produce the "octave harmonic" easily and clearly you will find, as indicated above, that, provided you continue bowing exactly at the same speed and with the same strength, you can lift away your finger and the harmonic will *still continue to sound;* for after the string has been divided into *two* segments it does not quite readily adjust itself

to a vibration of the *whole*. With practice, you can always play such passages as these—



without sliding down from the harmonic, or allowing the open G to sound between the two slurred notes. If, however, you should want to go at once to the open string—



all that is required is a little extra pressure with the bow, which will at once cause vibration of the *whole* string again.

42. If the preceding explanations have been understood the student can now make the following deduction: *If a stretched string, fixed at both ends, is halved, the sound the half will produce will be* ONE *octave higher than that of the whole string, and if the string is quartered the sound produced by the quarter will be* TWO *octaves higher than the whole, and so on to the smallest subdividing possible.*

43. Another important fact regarding the behaviour of stretched strings, but one much more difficult to understand than that described above, is as follows :—WHENEVER A STRING IS MADE TO SOUND (as by bowing on it, or striking or plucking it) IT VIBRATES NOT ONLY AS A WHOLE, BUT ALSO IN ALIQUOT PORTIONS OF THE STRING ($\frac{1}{2}$, $\frac{1}{3}$, $\frac{1}{4}$, $\frac{1}{5}$, etc.) SEPARATELY AND SIMULTANEOUSLY. It is from these divisions and sub-divisions of a string that harmonics of various sounds are produced *together with the fundamental note*, as already mentioned in PAR. 36.

44. The loudness or intensity of these harmonics is very subordinate to that of the fundamental, and many are, fortunately, quite inaudible as separate sounds without artificial means.[10] Fortunately indeed, for were it not so the sounds—say, of a violin—would be so blurred with discordant harmonics that they would be neither sweet nor pleasant. It has, however, been conclusively proved by the great German scientist Helmholtz that the inclusion of some of those harmonics, which, as we shall shortly prove, are, under special circumstances, distinctly audible, greatly enhances the *beauty and quality* of a fundamental note.

[10] There is a little instrument called the Resonator, invented by Helmholtz, which, when placed to the ear, will reinforce and audibly produce to the listener a harmonic which is in the air. The Resonator must be tuned to the exact pitch of the harmonic for which one is going to listen, and thus, with the help of several Resonators differently tuned, one is enabled to detect various harmonics which otherwise are inaudible, and of whose actual existence one would have no knowledge.

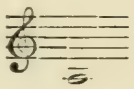
45. One of the harmonics which thus improves the quality of a sound is the "octave harmonic," the first of the series of harmonics *always present* when the fundamental note of a string is sounding, unless it has been struck, plucked, or bowed on at the *exact half*, as will be demonstrated later on. (*See* PAR. 100.)

46. The following experiment with the violin will prove the existence of the "octave harmonic" *together with a fundamental.*

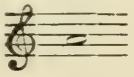
EXPERIMENT III.

A LOW STRING SETS A HIGHER STRING VIBRATING.

Tune the G string exactly to A—



and see that the upper octave open A—



is in perfect tune. Bow on the LOWER *string with fair speed and strength, and you will observe the* UPPER *string vibrating distinctly, and after a little practice you will be able to hear the two strings* SOUNDING TOGETHER. *This is because the lower A is producing its "octave harmonic" in the air, and the vibrations caused by the harmonic are communicated through the bridge of the violin to the string tuned exactly to the same sound, which is thus set vibrating and sounding in sympathy.*

47. A similar result to the above will be obtainable if, instead of raising the G string to A, your first finger is pressed on the note A of the G string tuned as usual. It must be remembered that directly the finger is pressed on the string the *new note*, produced by shortening the string, becomes the fundamental. At first, however, the vibrating string can be watched better if the left hand is not over it.

48. It is much more difficult to hear the harmonic if there is nothing at hand capable of producing the same sound. Thus, if you remove or flatten the upper A, you will very likely not be able to hear the harmonic when you play the lower A (unless your ear is very keen); because, although the harmonic will be still sounding, there will be no *sympathetic string* to *reinforce the sound.* Neither will you get a satisfactory result if you experiment with two violins held apart, as the atmospheric vibrations alone are not powerful enough, without the aid of a bridge, to

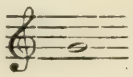
visibly demonstrate that there is any sympathetic communication of vibration between a harmonic and a string of a similar pitch *on another violin*.

49. Before leaving the violin there is one more highly interesting observation to make.

Experiment IV.

A high string sets a lower string vibrating.

Tune the D string to G—



Play on this "open" string as quickly and with as much strength as possible and watch the lower G string. You will see it vibrating in two segments with a node in the middle, and if you brush your bow quickly but lightly on to the lower G the latter will produce its octave! The vibrations caused by the G on the upper string were powerful enough to communicate themselves through the bridge to the string tuned an octave lower, and to cause that string to vibrate more in halves than a whole, so as to bring itself into unison with the sounding string.[11]

Experiments with the Pianoforte.

50. Our next experiments will be with the pianoforte. If you look inside you will see near the top of the strings a row of *dampers*, pieces of wood covered with a kind of thick felt, which rest on or against the strings for the purpose of stopping them from vibrating. When a note is played a small felted hammer strikes against its string, and simultaneously a damper is raised, and remains so until the finger is lifted from the keyboard, when the damper instantly falls again and the sound ceases. The highest strings have no dampers, because their vibrations do not continue long enough to require special means for stopping them. When the right or so-called "loud pedal" is pressed down *all* the dampers rise, and, as a consequence, any notes which are then played continue to sound together until the pedal is raised again and the dampers allowed to fall. This is the reason why in pianoforte playing special care should be taken not to keep the pedal down continuously through a change of harmony. As a means of strengthening the tone, the highest notes of most pianofortes are produced by three wires or strings

[11] This is not a *complete* scientific explanation of the reason; but it will quite suffice for the present purpose.

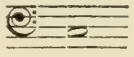
(*trichord*) tuned in unison. The lowest octaves generally have two wires or one very thick wire to each note.

51. We will now listen for the "octave harmonic" as produced from a pianoforte together with a fundamental.

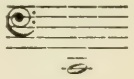
Experiment V.

A low string sets a higher string vibrating.

Silently press down, so as to raise or remove the damper,[12] *the note C—*

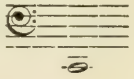


Now strike with fair force the C one octave lower—



allow it to sound for a second or two and then release it; still pressing down on the key-board the upper C. You will at once hear the OCTAVE *of the note you struck sounding quite audibly, and if you can touch the string*[13] *with, say, a piece of wire or steel you will notice how distinctly it is quivering. The moment the finger is raised the damper falls and stops further vibration, and the sound ceases.*

52. It should be now quite clear what caused the upper C to sound. Whilst the vibration of the *whole* string which was struck produced the fundamental C—



the string simultaneously divided itself into *halves*, and from the vibrations of these segments a harmonic one octave higher than the fundamental was produced. The harmonic was carried by the vibrating air, *together with the aid and through the medium of the sounding-board of the pianoforte*, to the string close at hand tuned to the same pitch, and the percussion and vibration were strong enough to set the string in motion. The above experiment should be repeated with various octaves, but the best

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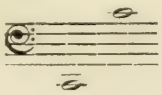
[12] On some grand pianofortes it is possible to raise the damper with the fingers; but if thus attempted it must be done very carefully.

[13] *String* is used throughout in preference to the plural. It makes no difference whether the particular note has one, two or three strings attached to it.

results will generally be obtained from fundamentals chosen between the following range of notes [14]—



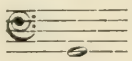
If you try to hear the harmonic without raising the damper of the sympathetic string it will not be nearly so distinct, and in many cases quite inaudible, as there will be nothing sufficiently free to naturally *reinforce the sound.*

53. Experiment IV. can also be most successfully performed on the pianoforte :—

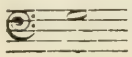
Experiment VI.

A HIGH STRING SETS A LOWER STRING VIBRATING.

Silently press down on the keyboard, say, the note G—



and then strike with some force the G one octave higher—



Lift away the finger from the HIGHER *G, and you will hear the* SAME SOUND *as you struck coming from the string of the* LOWER *octave which you are still pressing down. The reason is the same as that described in the case of the violin* (PAR. 49). *The lower string is dividing itself into two segments, and these are producing a sound one octave higher than that of the whole.*

54. There is an interesting method by which an "octave harmonic" can be heard *without a fundamental* on a grand pianoforte.

Experiment VII.

PIANOFORTE HARMONICS WITHOUT FUNDAMENTALS.

Open the lid of the pianoforte, and place a finger with moderate pressure on the exact half of a bass string (easily found by measurement), and ask someone to strike on the keyboard the note of the string you are touching. You will hear the sound of the upper octave with a peculiar bell-like tone, somewhat resembling

[14] The very rigid higher strings do not produce harmonics so well as the lower strings, which are not so tightly stretched.

that of a harmonic on a harp. If, with a small felted gong-hammer you lightly strike the string on EITHER *side of your finger you will obtain the same result; for your finger is forming a* NODE *at the centre of the string, and either of the two segments into which it is formed will produce the "octave harmonic."*

Whilst performing the latter part of the above experiment it will be necessary to get someone to raise the damper, either by silently pressing down the corresponding note on the keyboard, or by putting down the right-foot pedal.

Sympathetic Vibrations.

55. The following is a simple way by which the sympathy existing between strings tuned to the same pitch can be proved :—

Experiment VIII.

Open a pianoforte, put down the right-foot pedal, and then play a strong chord on the violin as near as possible to the pianoforte strings. As soon as you remove the bow you will hear the same chord reverberating with great clearness from the pianoforte strings, which are vibrating in sympathy. If a note is sung into the pianoforte, whilst keeping down the pedal, you will also hear it echo from a sympathetic string, and, further, you will observe that whenever you play with moderate strength, for example, D on the G string of a violin, the open D string begins to quiver in sympathy.

56. It was stated in PAR. 48 that the vibrations of air alone are, apparently, not strong enough to carry the vibrations *caused by a harmonic* from one violin to another. That they are strong enough to do so in the case of *fundamental notes* tuned in unison the following experiment will prove :—

Experiment IX.

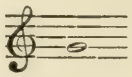
Tune two violins exactly together. Across the G and D strings of one violin place between the bridge and finger-board a little piece of thin paper about an inch long. Now bow with as much force as you can on the G and D strings of the second violin, holding it as close as possible to the first, and you will see the paper flutter along the strings—a certain proof that sympathetic vibration is going on.

57. Before leaving the "octave harmonic" it must be clearly understood that it can only be produced by "damping" the string in *one place*, causing thereby a division of the string into

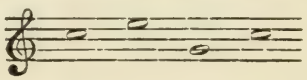
two segments, both of which produce the harmonic independently. Other harmonics, to be explained later on, can be obtained at two or more places on the same string, according to whether it is divided into thirds, quarters, etc. Another fact to keep in mind is that as a string cannot be divided into larger aliquot parts than halves, the "octave" is the *first and lowest* harmonic which can in any way be produced. In other words—THERE IS NO POSSIBLE HARMONIC BETWEEN A FUNDAMENTAL AND ITS OCTAVE. All the harmonics to be dealt with in subsequent chapters will be of a higher sound than the "octave," as they will have to be produced by dividing the string into smaller portions than halves; and it cannot be too clearly impressed on the student that THE SMALLER THE DIVISION OF THE FUNDAMENTAL STRING BECOMES, THE HIGHER IN SOUND WILL BE THE NOTE PRODUCED.

CHAPTER III.—THE "OCTAVE-FIFTH HARMONIC"

58. The preceding chapter was chiefly devoted to explanations and experiments in connection with the "octave harmonic." The student will doubtless have observed that when the octave G—



is played on the G string of the violin, the *pitch* of the note is exactly the same, whether the note is played as a harmonic or as a stopped note, but that the *quality* of the two sounds is not alike. The reason for the difference in quality between the two kinds of notes must be deferred for the present (*see* PAR. 113); but most of the harmonics which will be next explained will be found to be different in pitch, as well as in quality, from stopped notes played at the same parts of the string. By *pitch* is meant the height or depth of a sound. Thus, of these four notes—

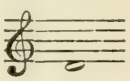


the second has a higher pitch than the first, and the third has the lowest pitch of the four, whilst the first and fourth have the same pitch.

59. The "octave harmonic" was produced by dividing the string into two segments. The next harmonic, that of the "octave-fifth," will be found when the string is divided into *three* aliquot parts.

EXPERIMENT X.

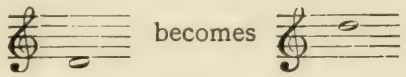
Measure off on the G string $4\frac{1}{3}$ *inches from the nut, and again from the bridge.*[15] *Put a chalk-mark on the finger-board at either place, and the division of the string-length into three parts will be easily seen. The first mark will be at the place where one plays D—*



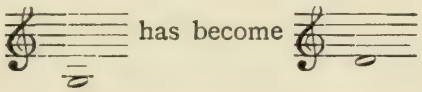
Now play this note D, first as a stopped note (the second finger in

[15] If any difficulty is found in measuring the string, an easy way is to cut a strip of paper the exact length of the string and to mark it in thirds, or any other required division, with a ruler or compasses. Place the paper under the strings and chalk the edge of the finger-board on the side of the G string at the proper places. This will be found an excellent plan if it is desired in experimenting to divide the string into very small portions.

the third position will be the best to use), *by pressing the finger, and secondly, as a harmonic, by touching the same spot on the string lightly, and you will notice the pitch of the note changes to that of an octave higher :—*



60. Why is this ? The answer is most important. When the D is played as a stopped note the portion of string *below* the finger does not vibrate or sound, but the remainder (*i.e.*, *two-thirds*) of the string, from the bridge to where the finger is placed, *vibrates as a whole*. The finger having, as it were, cut off one-third of the whole string, the pitch has been raised the interval of a perfect fifth—



But when the same spot is "damped" for a harmonic, not only does the string below the finger vibrate, but the upper two-thirds of the string *subdivides itself into two equal segments*. Watch the string in a good light whilst you play the harmonic strongly with a very straight bow near the bridge, and you will observe that just at the places where the two chalk-marks are placed the string is, apparently, not vibrating.[16] The fact is the string is divided into three equal segments, divided by two *nodes*—

consequently each of the three segments is *vibrating independently*, and producing a note, the pitch of which is the same as if the string had been actually shortened to ONE-THIRD of its entire length. Thus we arrive at the following fact: WHEN NODES ARE FORMED BY "DAMPING" A STRING, ONLY A NOTE CORRESPONDING IN PITCH TO THE SIZE OF THE SEGMENT BETWEEN THE NODES CAN BE OBTAINED.

61. The following Experiment will prove the above :—

EXPERIMENT XI.

THE SAME HARMONIC PRODUCED AT TWO NODES.

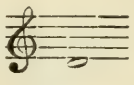
Place your finger lightly on the string at the HIGHER *node, and you will find that the pitch and quality of the note produced there*

[16] It would not be correct to say that a *node* is an *absolute* place of rest. There must be a slight vibration running through, otherwise the pieces of string between the *nodes* could not vibrate at all.

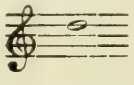
are exactly the same as those of the harmonic produced from the LOWER *node. Moreover, if you get someone to "damp" one node whilst you "damp" the other no alteration of sound will take place; it will remain precisely the same. If you place the violin on a table you can further prove what was mentioned in the case of the "octave harmonic," that when you "damp" either or both of the nodes the harmonic can be produced by bowing on any one of the three segments.*[17]

62. The student will now have no difficulty in agreeing with the following summary: WHEN ANY PART OF A STRING IS "DAMPED" AT ONE OF ITS ALIQUOT DIVISIONS IT INSTANTLY FORMS OR GROUPS ITSELF INTO SEGMENTS, OF A NUMBER CORRESPONDING TO THE LENGTH OF THE DIVISION TOUCHED, WITH NODES DIVIDING THE SEGMENTS. Thus, "damp" a string at the $\frac{1}{2}$ and two segments with one *node* are formed; "damp" it at $\frac{1}{3}$ from *either end* and three segments and two *nodes* are formed; "damp" it at the $\frac{1}{4}$ from either end and four segments with three *nodes* will be the result; and so on, as far as is feasible. How far on the violin these divisions are feasible will be shown later. (*See* CHAP. viii.)

63. It will be of great assistance to the study of violin harmonics if it be remembered that the pitch of a harmonic always corresponds to that of a stopped note played at the same distance from the bridge as the length of one of the segments into which the string is divided. Thus, D—



played at $\frac{1}{3}$ from the *nut* as a harmonic on the G string is of the same pitch as the note an octave higher—

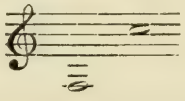


but when this latter note is played at the distance of $\frac{1}{3}$ from the *bridge* the pitch is the same, whether the note be played as a harmonic or as a stopped note.

64. The following experiment will prove that the "octave-fifth harmonic" sounds together with a fundamental string.

EXPERIMENT XII.

Tune very perfectly the G string to F and the A string to C—



[17] As this rule applies to all natural harmonics it will not be given again.

Play on the open F string with good force, and you will not only see the C string vibrating, but you will be able to hear the C sounding. The same result can be obtained, but not so clearly, if the strings are tuned to their usual notes and the note D is stopped on the A string, whilst the bowing is continued on the open G string.

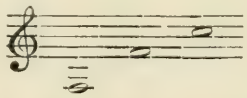
65. After the ear has been directed to listen for this harmonic one will often hear it together with the fundamental when a low note is played on the G string, even without an upper string tuned or stopped to the necessary pitch for reinforcing it, as the pitch of the harmonic being of a different character to the fundamental it is more easily distinguished than the "octave harmonic."

66. To prove that the "octave" and "octave-fifth" harmonics *sound together* with a fundamental is not quite so simple as the preceding experiment, but it can be accomplished in either of the two following ways :—

Experiment XIII.

TWO HARMONICS SOUNDING TOGETHER.

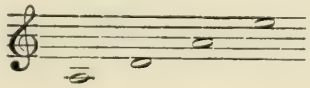
(1) *Tune the three lowest strings to F, F, C, thus—*



Play with strength and speed on the lowest open F string, and you will see the upper F and C strings vibrating, and after a little practice you will be able to hear the two notes sounding together.

Experiment XIV.

(2) *Tune the G string to A, and the other three to their usual notes D, A, E—*



Play on the lowest A string, and it will cause the upper A and E strings to vibrate. But the E string being thinner and stretched more tightly than the others does not oscillate so noticeably, and you may find it difficult to perceive any vibration. If so, take a little piece of thin paper, about an inch square, bend it over and place it on the E string between the bridge and finger-board. The moment you begin to play the low A the paper will dance violently and then fly off the string, a clear proof of the intensity

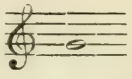
of the vibration actually going on. If you tune the G string, say, to G sharp, and replace the paper either on the A or E string, you can continue bowing up and down on the G sharp without dislodging the "rider" (as the paper may be termed), because G sharp does not produce either the A or E as a harmonic.

67. In the latter part of the above experiment there will be a slight fluttering of the "rider," but this will arise from the fact that the bridge *always* vibrates when *any* note is played. A mute pressed on the bridge has the effect of partially stopping its vibrating powers, and thus it deadens and decreases the tone.

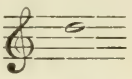
68. The following Experiment will again prove how a higher string sets a lower string vibrating in unison by sympathetic resonance :—

EXPERIMENT XV.

Tune the D string to G—



as shown in Experiment IV., and stop D



on the same string (with the second finger in the third position). Play this latter note with strength and speed, and you will see the open G string vibrating in three segments, and if you brush the bow rapidly but lightly on to the G string you will find the latter will produce the same D in unison with the note you were just playing on the third string.[18] *The reason of it doing this is of the same character as described in Experiment IV.*

69. A similar result to the above, but one not so clearly demonstrated, is produced when, in the usual way, D on the A string is played. It is worth noticing, too, when the G string is tuned to A, how different the quality of the upper open A and E strings is, as compared to when the lowest string is tuned to G. This difference is brought about by the fact that, with the G string tuned to A, when either of the upper strings is played, or even if the two are sounded together, the low A *responds in unison*

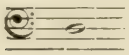
Experiments with the Pianoforte.

70. The "octave-fifth harmonic" should be listened for on the pianoforte as described for the "octave."

[18] This experiment can also be shown by strongly playing the upper octave D on the D string when the latter is tuned to its *usual* pitch.

Experiment XVI.

Silently press down, or raise the damper of, the note D—



and then strike with good force the G one octave and a perfect fifth lower—

After a second or two lift the finger away from the G and you will hear the D sounding. The reason for this should be readily understood. The string of the note which was struck, besides vibrating as a WHOLE, *vibrated also in* THREE SEGMENTS. *The vibrations from these segments produced a harmonic corresponding to the pitch of the note D being held down, and consequently its string was set vibrating.*

Experiment XVII.

THE "OCTAVE-FIFTH HARMONIC WITHOUT THE FUNDAMENTAL."

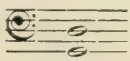
On a grand pianoforte follow the same directions as given in Experiment VII., only in this case the string must be pressed at the distance of one-third from either end.

71. The "octave" and "octave-fifth" harmonics can also be heard sounding together on the pianoforte.

Experiment XVIII.

TWO HARMONICS SOUNDING TOGETHER.

Silently press down G and D—



and strike the G an octave lower, as before. Release it, and the two upper notes will be heard sounding together.

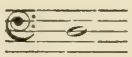
72. Still more interesting, perhaps, is the next experiment.

Experiment XIX.

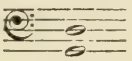
TWO HIGH STRINGS SET ONE LOWER STRING VIBRATING IN DIFFERENT DIVISIONS.

First silently press down the note G—

and strike with force the D an octave and fifth higher—



Release the D after a second or two and the SAME SOUND *will be heard coming from the G you are pressing down. The string of the latter note has divided itself into three segments, from the same cause as briefly described in Experiment VI. Now silently press down the same low G as before and strike the* TWO NOTES *G and D—*



Release these and the SAME TWO SOUNDS *will be heard proceeding from the low G string you are pressing down. The vibrations of the two notes which were struck set the low G string vibrating, and forced it to divide itself both into* HALVES *and* THIRDS. *To prove that this is correct you have but to lift the finger away from the note of the low G, and, as the damper falls on the string, the sounds cease.*

73. The above experiment helps to prove the remarkable fact that strings divide themselves simultaneously into segments of various sizes, and produce various sounds at one and the same time. This may be hard to realise, but it is certainly a fact.

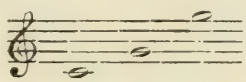
74. As there is no possible even division of a string between $\frac{1}{2}$ and $\frac{1}{3}$, there is no "natural" harmonic to be produced between the two already described. The so-called *artificial harmonics* which can be used on the violin for the intermediate notes between the "octave" and "octave-fifth" are explained in CHAP. IX.

CHAPTER IV.—THE "DOUBLE-OCTAVE HARMONIC."

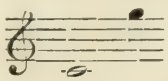
75. The next harmonic in the series produced by vibrating strings is obtained by the division of a string into *quarters*. Recalling the rule given in PAR. 42, that the half and the quarter lengths of a stretched string produce notes the pitches of which are respectively one and two octaves higher than that of the whole, it will be evident that the harmonic to be produced from the quarter of a string will be *two octaves* higher than that of the fundamental.

EXPERIMENT XX.

Adopting the plan previously described, divide the violin G string into four divisions, $3\frac{1}{4}$ inches apart, and make a chalk-mark on the finger-board at each place. There will thus be marks at $\frac{1}{4}$, $\frac{1}{2}$, and $\frac{3}{4}$, measuring from the nut. The stopped notes produced at these quarters will be C, G, G:—



Play the note C first as a stopped note, and then as a harmonic, and you will hear the pitch change from C to G—



two octaves higher than the fundamental open G.

76. The stopped note C will be produced by the vibration of three-fourths of the string from the bridge to where the finger pressed the note; but the harmonic G will be produced through the string dividing itself into *four equal segments*, each of which produces the harmonic independently:—

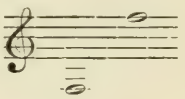
Watch the string in a good light and you will be able to see a *node* formed at each of the three chalk-marks whilst the harmonic is being played. So long as the string is thus divided into quarters, all, or any two of the three *nodes* can be "damped" at the same time, and no change of pitch will take place. The same sound is produced, too, if either the $\frac{1}{4}$ or $\frac{3}{4}$ *node* is "damped" separately, and observe, as in the case of the "octave-fifth," that the string at the highest division produces the same pitch either as a harmonic or as a stopped note.

77. If, however, the $\frac{2}{4}$ *node* is "damped" *alone*, the result will not be the "double-octave," because the string will then vibrate in *halves*, and the "octave" will be produced. One cannot, of course, produce two different harmonics at the same *node;* therefore, WHEN TWO OR MORE DIVISIONS OF A STRING ARRIVE AT THE SAME PLACE, THE HARMONIC ACTUALLY PRODUCED THERE WILL ALWAYS BE THE ONE WHICH BELONGS TO THE NODE WHICH IS FORMED WHEN THE STRING IS IN ITS LARGEST DIVISION. A moment's reflection will show that some of the *nodes* of the smaller divisions must necessarily be the same as those of larger ones; thus $\frac{2}{4}$ is the same as $\frac{1}{2}$, and $\frac{2}{6}$ and $\frac{4}{6}$ will be the same as $\frac{1}{3}$ and $\frac{2}{3}$, etc.

78. The higher the pitch of a harmonic becomes, the more difficult it is, as a rule, to hear it together with a fundamental; but the following experiment on the violin will suffice to prove the existence of the "double-octave":—

Experiment XXI.

Tune the G and E strings to F, two octaves apart—



and place a small paper "rider," as described in Experiment XIV., on the highest string. Play on the lowest string with strength and speed, and the "rider" will at once dance violently and then fly off.

Experiment XXII.

To prove that the high F will make the low F vibrate, the "rider" should be placed on the lowest string. Now bow with strength and speed on the highest open string, and the "rider" will again fly off, as the string on which it was placed is dividing itself into four segments, thereby vibrating in unison with the note being played.

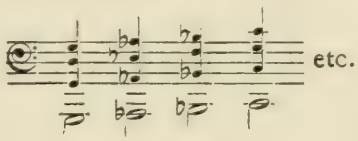
Experiments at the Pianoforte.

79. The "double-octave harmonic" can also be heard on the pianoforte, as already fully described. Either silently press down any bass note and then strike the note two octaves lower and release it, as explained before, or lightly press any bass string with the finger at one-fourth of its length from either end, and get someone to strike the same note as you are pressing.

EXPERIMENT XXIII.

THREE HARMONICS SOUNDING TOGETHER.

In the following examples first silently press down the crotchets and strike the minim, and you will hear the three harmonics sounding together when you lift your finger away from the note you struck, the others remaining down. Next silently press down the minim and strike the crotchets, and, as you release the LATTER, *you will hear the* SAME THREE SOUNDS *proceeding from the string of the minim note you are still pressing down. Notice that the fifth in the chord must always be a* PERFECT *fifth :—*



CHAPTER V.—THE "MAJOR-THIRD HARMONIC."

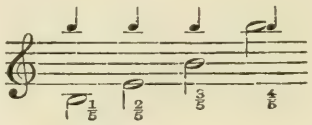
80. By the division of a string into fifths a new and very interesting harmonic, that of the "major-third," is produced.

Experiment XXIV.

THE SAME HARMONICS PRODUCED AT FOUR DIFFERENT NODES ON THE SAME STRING.

Mark the finger-board of the violin, as before, at distances of $\frac{1}{5}, \frac{2}{5}, \frac{3}{5}, \frac{4}{5}$ *from the nut end. There will now be five segments with four nodes shown, and as none of these nodes come at places which we have already marked in the previous experiments, it will be obvious that the new harmonic can be produced at* FOUR DIFFERENT PLACES *on the same string:—*

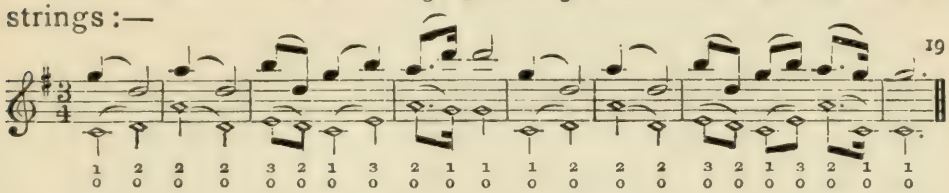
In the following example the minims show the stopped notes which will be produced at the four chalk-marks, and the crotchets the harmonic coming from the same places:—



Now play, for example, the second note, E (with the third finger in the third position), as a stopped note, and then as a harmonic, and you will hear the pitch change from E to B, two octaves and a major third higher than the fundamental G. "Damp" the string at any fifth singly, or at any or all of them together, and the sound remains precisely the same.

81. When this harmonic is required in violin playing it is generally taken at the distance of $\frac{2}{5}$ from the nut, as it is often used in combination with those formed at $\frac{1}{4}$ and $\frac{1}{3}$; but it should be practised at each *node*. The following short passage

introduces harmonics at the $\frac{1}{3}$, $\frac{1}{4}$, and $\frac{1}{5}$ divisions of the G and D strings :—



82. The above and similar harmonics are generally printed with somewhat diamond-shaped heads, as a distinguishing sign that the *pitch* of the note is different from its apparent position on the stave. The actual sounds produced are usually given above the harmonics in ordinary notes, which also serve to show the correct time-value of the harmonics. Violinists do not need to be told that the fingering for a harmonic always includes the sign of a cypher—o.

83. The "major-third harmonic," at first, will be found somewhat more difficult to produce on the violin than those previously given. The reason is that, as the divisions of a string become more minute, the harmonics crowd more closely together, and the *nodes*—on which the "damping" *must* take place—become correspondingly smaller. For example, the *node* which forms at the half of the string for the "octave" is about an inch long, and quite easily seen, but those formed at the fifths are so small as to be almost invisible in an ordinary way. Much more exactitude is necessary, therefore, in placing the tip of the finger at the precise spot, or else another and quite unexpected harmonic will make its appearance!

84. Those who are not far advanced in the playing of harmonics will probably find that the simplest method of producing the "major-third" at each of the four *nodes* will be by adopting the plan previously suggested—namely, of placing the violin on a table and "damping" the string at each *node* with the feathery part of a quill pen.

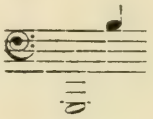
Experiments at the Pianoforte.

85. The "major-third harmonic" can be heard on most good pianofortes in the same way as other harmonics; but on cottage pianofortes and very old instruments it is sometimes difficult, or even impossible, to distinguish it.

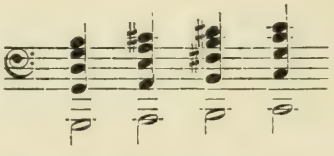
---

[19] When first beginning to play harmonics, young players are often much puzzled by finding that a *lower* note produces a higher sound than a *higher* note, as in the case of the first two notes in the example given above. The reason should be quite clear to those who have followed the preceding experiments. For the first note the string vibrates in *quarters*, but for the second it vibrates in *thirds*, and the quarter of a string produces a higher sound than the third of its length.

86. The note to be pressed down must be two octaves and a major third above the note which is struck—



87. It will considerably assist the ear in listening for a particular harmonic, if the sound to be picked out is first of all softly played alone. Thus, in the preceding example, first softly play the B; then, when the sound of it has quite died away, silently press down the same note and strike the G. When you lift away your finger from the latter note you will probably be able to easily detect the sound of the B again. If you fail in this case, try other notes before giving up the attempt, as some strings will produce the harmonics better than others. The fundamental note should be struck firmly, and kept sounding for about three seconds, and instead of a single note an octave can be struck in the bass. If the pianoforte experimented upon will produce this harmonic with sufficient distinctness for it to be heard at all, it can also be distinguished together with the three earlier ones.[20] You will thus be able to prove this interesting fact—that A COMPLETE MAJOR CHORD IS PRODUCED BY HARMONICS WHENEVER A FUNDAMENTAL STRING IS SOUNDING. The following example shows the notes to be silently pressed down, and the fundamental to be struck. A lower octave may be added to the minim:—



Tierce de Picardie.

88. The natural production of the major third as a harmonic is probably the reason why, especially in older music,[21] so many compositions in minor keys, by the old cathedral masters, close with a major tonic chord (known, without any apparent reason,

[20] Harmonics are not always so distinctly heard in quite new pianofortes as in those which have had a little use. The harder the hammer hits the string the clearer, as a rule, will be the harmonics. New hammers are softer than those which have been worn, by reason of the felt covering on them not being cut through with use.

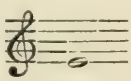
[21] Although the old composers probably knew very little, if anything, about the theory of harmonics sounding with a fundamental, their ears would, nevertheless, be very alive and keen to anything in the nature of a dissonance, as their harmony was far more simple and free from discords than that of modern composers.

as the *Tierce de Picardie*, or *Picardy Third*). The use of the Major Tonic Chord avoids the slight dissonance (naturally more noticeable in a final chord) of the major third sounding (as a harmonic) together with the minor third, as is the case when a minor chord is employed.

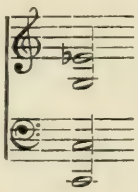
89. Anyone with a keen musical ear and who has had some practice in listening to harmonics, or in analysing sounds, etc., will be able, in the following way, to hear on a good pianoforte the slight ill-effect of the dissonance described above.

EXPERIMENT XXV.

Silently press down, say, E natural—



then strike with force the following chord—



Keep it sounding for about two seconds, or a trifle longer, and then release the THREE *lowest notes. It will be quite possible to detect the E natural sounding together with the E flat which is still being pressed down. Now put down the right-foot pedal and strike the chord again—C, C, G, E flat—without pressing down the E natural, and if you listen with your ear as close as possible to the strings of the pianoforte, you will be able to hear a distinct jarring produced from E flat and E natural sounding together.*

90. Sufficient evidence of the use of the *Tierce de Picardie* will be found by examining the closing chords of the preludes and fugues in minor keys in Bach's immortal "Forty-eight," and of the "Amens" to hymn tunes in minor keys.

91. The "major third" will be heard perfectly easily without the fundamental by pressing a bass string at $\frac{1}{5}$, $\frac{2}{5}$, $\frac{3}{5}$, or $\frac{4}{5}$ from either end, as described for the earlier harmonics. A continuation of the latter part of Experiment XXIII. is hardly practicable, but it might be tried on a good pianoforte.

92. An excellent way of hearing the combined harmonics produced from a fundamental string on a grand pianoforte is as follows.

Experiment XXVI.

COMBINED HARMONICS SOUNDING TOGETHER.

Put down the right-foot pedal and strike a fairly deep bass note. Allow it to sound for about four seconds, and then stop its further vibration by pressing something (a handkerchief or a violin pad will serve admirably) on the string of the note you struck. A beautiful soft major chord will be heard coming from the strings which have been set vibrating in sympathy with the harmonics produced by the ONE *fundamental which was sounded. The sound will, of course, cease as soon as you lift up the pedal and allow the dampers to fall. The effect will be still better if you strike an octave in the bass and then stop the vibrations of the two strings as before.*

93. After a little practice in the above experiment it will be thoroughly clear to the student what is meant when it is stated that a string does not merely produce a *single* or purely *simple* tone, but a *composite clang* of many sounds. The experiment will still further prove how important a part the right-foot pedal plays in pianoforte tone-production. Not only does it serve, when pressed down, to sustain sound, but it also considerably brightens and enriches the tone, by allowing the free sympathetic vibration of strings tuned to the various pitches of the harmonics emanating from the notes which are struck.

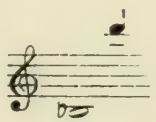
CHAPTER VI.—THE "DOUBLE-OCTAVE-FIFTH HARMONIC."

94. A very short explanation should suffice for the next harmonic, that of the "double-octave-fifth." It is produced by dividing a string into six segments, and the pitch of the note will be one octave higher than that obtained when the string is divided into thirds. This rule applies throughout the whole series of harmonics, that THE MULTIPLE OF ANY DIVISION PRODUCES A NOTE AN OCTAVE HIGHER THAN THAT OF THE LOWER DIVISION. Thus, $\frac{1}{4}$ of a string is an octave higher than $\frac{1}{2}$; $\frac{1}{6}$ is an octave higher than $\frac{1}{3}$; $\frac{1}{8}$ is an octave higher than $\frac{1}{4}$; and so on. As each division occurs for the first time,—such as $\frac{1}{5}$, $\frac{1}{7}$, $\frac{1}{9}$, etc.—a *new harmonic* with quite a different pitch is produced.

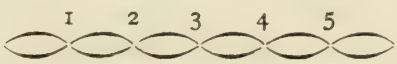
95. The following experiment should prove interesting:—

EXPERIMENT XXVII.

Divide the G string of the violin into six divisions. The $\frac{1}{6}$ from the nut will be where one plays B flat, and the $\frac{5}{6}$ will be just above the finger-board. Now play the low B flat as a stopped note and then as a harmonic, and it will be noticed that the pitch changes from B flat to D, two octaves and a fifth higher than the fundamental G—



This harmonic can only be produced singly at the two extreme nodes, $\frac{1}{6}$ and $\frac{5}{6}$, as the $\frac{2}{6}$ and $\frac{4}{6}$ are the same as $\frac{1}{3}$ and $\frac{2}{3}$, and the $\frac{3}{6}$ is the same as $\frac{1}{2}$. It is quite possible to "damp" with two fingers, say, the $\frac{1}{6}$ and $\frac{2}{6}$ nodes. The string will then be divided into six segments—

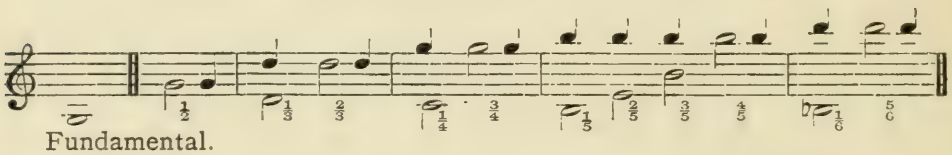


and will produce the high D, as just shown. Now lift away the finger from the LOWER *node, and the string instantly groups itself into three segments—*

and the pitch of the harmonic drops an octave.

96. This harmonic completes the *natural* harmonics in fairly general use on the violin. The following table gives them in a

complete form on the G string. The minims represent the stopped notes and the crotchets the harmonics. The figures give the measurements of the string, counting from the nut, the *lower* figure always indicating the number of segments into which the string is divided. It should be remembered that the number of *nodes* is always one less than that of the *segments*.



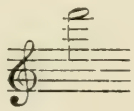
Fundamental.

The student is advised to make similar tables for the other strings, and to practise the harmonics at all the various places on the four strings.

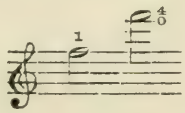
97. The "double-octave-fifth" co-mingles with the other harmonics as described in Experiment XXVI., and it can also be heard by itself on the pianoforte in the same way as has been already explained for the others.

CHAPTER VII.—THE "MINOR-SEVENTH HARMONIC."

98. The next harmonic, produced by dividing a string into seven segments, although rarely met with, requires special notice for various reasons. It will be advisable, although perhaps troublesome, to measure the violin G string as before, and to mark it this time in seven equal divisions. When this is done it will be found that all of the first five *nodes* ($\frac{1}{7}$ to $\frac{5}{7}$) fall *between* notes which are used in playing. Thus $\frac{1}{7}$ comes between the semitones A and B♭; $\frac{2}{7}$ between C and C♯; and so on. With practice it is quite possible to produce the harmonic at all these *nodes;* but when the harmonic is used in playing it is always taken at the highest ($\frac{6}{7}$) *node*, which will be found about half-an-inch *above* the finger-board. Place the tip of the finger lightly on the exact spot, and play with the bow near to the bridge, and the harmonic will ring out clearly. The pitch of the note will be that of F, two octaves and a minor seventh higher than the fundamental open G—



99. There is a peculiarity about this harmonic which will be at once apparent to a musical ear, namely, it is somewhat *flatter* than the correct note of the scale. There is no possible way of overcoming this flatness, and it is hardly sufficient to debar the occasional employment of the harmonic. The flatness can be noticed by testing the harmonic with the corresponding note of the pianoforte, or by playing first the lower octave and then the harmonic on the G string:—



100. The minor-seventh harmonic cannot, as a rule, be heard together with a fundamental on a pianoforte, for a very important reason. It is a dissonant harmonic in two respects, being not only a trifle flat, but forming a *dissonant* interval (that of the minor seventh) to its fundamental; unlike all the previous harmonics, which formed *consonant* intervals. It has been proved by experience that its inclusion as a harmonic does not improve the tone-quality of the lower notes of a pianoforte—rather the reverse—and therefore the hammers of the bass notes

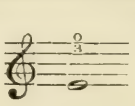
are arranged so that they shall strike the strings at a distance from the top pin of about $\frac{1}{7}$ to $\frac{1}{9}$ of their whole length. By so doing the possibility of a *node* forming at this particular place is destroyed, for, WHEREVER A STRING IS PLUCKED, STRUCK, OR BOWED, NO HARMONIC WHICH REQUIRES THAT SPECIAL SPOT FOR ONE OF ITS NODES CAN FORM.[22]

101. There are several simple ways in which the above important fact can be demonstrated.

EXPERIMENT XXVIII.

HOW TO PREVENT THE FORMATION OF A HARMONIC.

Divide the violin G string once more into fifths. Play in the usual manner, say, the harmonic at the second $(\frac{2}{5})$ *node—*



with the bow placed about an inch from the bridge. Now, whilst still "damping" the note E for the harmonic, shift the bow on to the $\frac{4}{5}$ *node, and it will be found impossible to produce any musical sound. The string being bowed on at one of its even divisions, no node can form at that spot, consequently, no harmonic which requires that place for one of its nodes can be obtained. Shift the bow a very small degree either above or below the node, and the harmonic will "speak" again. If, whilst bowing on the* $\frac{4}{5}$ *node, the finger is pressed tightly on the string at E, the stopped note will of course sound; or, again, if the string is "damped," say, at* $\frac{1}{2}$ *or* $\frac{1}{4}$*, either of the harmonics which belong to those divisions can be obtained, as neither of them forms a node at one-fifth of the string.*

102. The above experiment will demonstrate an important matter regarding the placing of the bow in violin playing. The nearer the bow is brought to the bridge (of course in moderation) the clearer and louder will be the sound produced, for the fundamentals will be accompanied by many harmonics which serve to brighten the tone; but the nearer the bow is brought to the finger-board the duller and softer will be the sound, because several harmonics will be excluded from participating in the tone.[23] Playing on the open strings, the only harmonics

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[22] The minor-seventh harmonic can sometimes be heard proceeding from the *covered* bass strings of a grand pianoforte. The covering somehow seems to re-establish the vibrations which were stopped by the first blow.

[23] It must also be borne in mind that the mere fact of placing the bow over the finger-board instead of over the sound-holes will serve to considerably cloud the tone.

excluded by placing the bow anywhere between the bridge and the finger-board are those beginning from the sixth division upwards; but when notes are stopped higher up the string, some of the earlier and more important harmonics might be easily destroyed by placing the bow too near the finger-board; hence the following may be taken as a general recommendation :—*The higher the fingers are placed on the strings the nearer the bow may come to the bridge.*

103. To make the above remarks still clearer, the violin student is advised to try playing, say, the opening eight bars of Raff's "Cavatina" on the G string, and to notice the difference in the quality of tone produced (i.) with the bow placed throughout the phrase at the distance of half-an-inch below the finger-board; (ii.) just above the finger-board; (iii.) midway between the bridge and finger-board.

Experiments at the Pianoforte.

104. A further striking demonstration of the variety in tone-quality which can be produced from the same string according to the place where it is struck, can be observed on a grand pianoforte.

Experiment XXIX.

VARIOUS TONE-QUALITIES PRODUCED FROM ONE STRING.

Open the lid of the pianoforte, and get someone to press down on the keyboard the corresponding note of any bass string.[24] *Now with a small felted gong hammer strike the string of the note that is being pressed at different distances, beginning from just above the end pin until the exact middle is reached, where a white chalk-mark might be placed.*[25] *Various qualities of tone will be observed; but that produced at the centre will be very unsatisfactory, being dull and thin instead of rich and grand. This will be occasioned by the fact that the string, being struck at the middle, no node can form there, and consequently the harmonics of the* $\frac{1}{2}$, $\frac{1}{4}$, $\frac{1}{6}$, *etc., are destroyed. The harmonics formed at the* $\frac{1}{3}$, $\frac{1}{5}$, *etc., will not, however, be interfered with, and can be heard very distinctly. If the string is struck close up to the end pin the tone will be shriller, as the discordant 7th and 9th harmonics will join in the "composite clang" of the fundamental, and only when the string is struck at the same distance from the end as the hammer is from the top will the best quality of tone be produced.*

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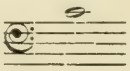
[24] Or the ivory key can be kept pressed down by a weight.

[25] This will be useful in the next experiment.

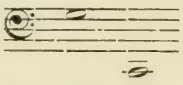
105. The following is another and more visible way of proving the preceding facts.

Experiment XXX.

Cut a small, flat piece of cork and place it along the string of, say the bass note C—



of a grand pianoforte. Press down the corresponding note on the keyboard, and then strike the C one octave lower, and the cork will be violently agitated, for reasons explained in Experiment V. Now replace the cork and continue to press down the same note; but instead of sounding the lower octave in the usual way strike the string with the gong hammer. So long as the string is struck anywhere except at the middle the cork on the strings of the note an octave higher will continue to be agitated; but when you strike at the exact middle the cork will remain quiet, because the struck note cannot then produce its octave harmonic. In the same way you can place the cork on, say, G, and strike the same C as before—



at the distance of $\frac{1}{3}$ from either end, and the cork will remain quiet. But strike the C in the middle and the cork will be agitated again, as the harmonic at the third division has of course no node in the middle of the string.

106. The reason why a *node* does not form at the actual point where the string is struck, etc., is because, being necessarily most violently agitated at that particular spot, the string cannot be sufficiently at rest there to form a *node*.

107. To attempt a scientific explanation of the reason why strings subdivide themselves into vibrational portions at the same time as they vibrate in their whole, would go beyond the purpose of this elementary treatise.[26] The following simple explanation may, however, be of service, although it is practically impossible to picture in one's mind what really happens. When a string is fixed at both ends, as in a violin, pianoforte, harp, etc., a succession of what may be termed *sound-waves* travels along the string whenever it is struck, plucked, or bowed. As the first of these waves reaches the fixed end it is reflected (that is to say, it is driven back again when further progress becomes impossible),

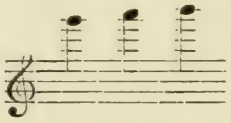
[26] A list of more advanced works on the subject is given at the beginning.

and in returning it meets another wave coming from the opposite direction. The two waves cannot pass each other; but as they meet one is pushed to the right and the other to the left, with the consequence that the exact point of meeting, being urged by equal forces in two opposite directions at the same time, will not move in either direction, and becoming thus stationary, produces a *node*. As soon as this occurs the *sound-waves* become reflected from the *node* as well as from the fixed ends,[27] and consequently a series of *nodes* quickly forms with harmonics sounding from the vibrating segments between them

[27] The fixed ends of strings do, in reality, form *nodes* themselves.

CHAPTER VIII.—THE HIGHEST NATURAL HARMONICS.

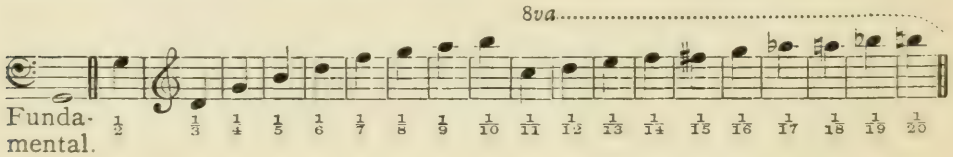
108. Occasional use is made on the violin of harmonics produced by dividing the string into eight, nine, and ten segments. These can only be taken at the *nodes* close to the bridge, for the reason given in PAR. 98. The pitch of these three notes on the violin G string will be G, A, B, respectively :—



The G and B are octaves to those formed by dividing the string into quarters and fifths; the A forms a new harmonic as regards pitch.

109. It cannot be said that even these are the highest harmonics which can be heard, for by placing, say, the edge of a thin coin on the string quite close either to the bridge or nut, whilst the extreme side of the bow-hair is brought almost on to the bridge, it is possible to continue producing them as far as the sixteenth division. Needless to say, these latter notes cannot be used in playing, and are only interesting in experimenting. These high harmonics can also be heard, without fundamentals, on a grand pianoforte by moving the finger at various minute distances along the portion of string above the hammer (or near the end pin), striking the string in the usual manner at each separate distance.

110. From very long strings harmonics can be produced even to the twentieth division. The following table gives a complete list of the whole twenty. In consequence of the height of the top notes the open G string of the violoncello, instead of the violin, has been taken as the fundamental :—

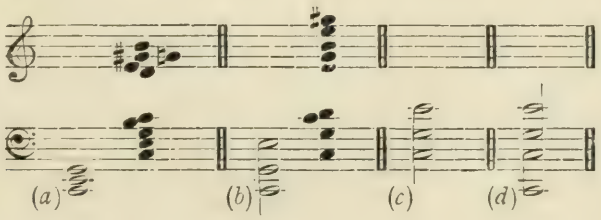


111. A few of the above notes are a little flatter, and others somewhat sharper than the corresponding notes in general use. It will be very apparent, on looking at the above table, how much more closely the harmonics crowd together as the division of the string becomes smaller. Between the fundamental and its first octave there is no harmonic; between the first and second

octaves there is one; between the second and third there are three; between the third and fourth there are seven; and between the fourth and fifth there would be fifteen, or more notes than are used in the octave in what may be called civilised music.[23] The reason for this constant *drawing together* of the harmonic is very simple if it be remembered that the octave to any note is its exact double in number, and that a new harmonic, as far as pitch is concerned, appears at *every* aliquot division of a string. Therefore, the C at $\frac{1}{11}$ will have its octave at $\frac{1}{22}$, and as B♮ comes at $\frac{1}{20}$ there must be an intermediate sound between B♮ and C at $\frac{1}{21}$, and so on.

Chords and Conflicting Harmonics.

112. Before leaving the subject of natural harmonics, it may be of interest to point out what an important part they play in chord combinations. Those who have followed the experiments in the previous chapters will have noticed that the higher the fundamental is, the less distinctly will the upper harmonics be heard. It is obvious that a major triad produces very dissonant harmonics, the harmonic fifth of the third of the chord, for instance, forming a major seventh to the tonic. If the three notes of a triad are placed close together in the bass their harmonics produce a bad effect; but if the chord is spread out so that the third is placed higher, say, than the fifth the ill-effect is scarcely noticeable, as the high harmonics are not so acutely heard. This will be at once apparent if the two following chords *a* and *b* are struck separately on a pianoforte, with the pedal pressed down. The chords should be listened to with the ear near to the strings. The small notes in the examples give the first four harmonics of each note. The chords sound still better if played as at *c* or *d*, in which case the harmonics will be an octave higher than at *b*:—



Summary of Facts about Harmonics.

113. Before proceeding to the artificial harmonics it will be as well to tabulate the principal and most important facts about harmonics in general.

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[23] In Arabian and Persian music, for example, relations of intervals are met with that are not employed in European or modern music.

HOW HARMONICS ARE PRODUCED.

(*a*) When a string is "damped" (lightly touched) at one of its aliquot (even) divisions the result is to *destroy the fundamental note*, and to bring out with greatly increased prominence a harmonic (overtone, or partial) which is always naturally present and sounding (but in an extremely subdued form) whenever the fundamental is freely vibrating.

NATURAL HARMONICS.

(*b*) No note can be produced as a *natural* harmonic unless it is one of the series of harmonics which sound together with a fundamental; therefore it is not possible to produce a natural harmonic on the G string *between* any of those given in the table in PAR. 110.

COMPOSITE CLANGS AND SIMPLE TONES.

(*c*) It has been demonstrated that fundamental notes are *composite clangs* of various sounds. Harmonics, however, more nearly approach *pure simple tones*, and hence arises the *difference in quality* between stopped notes and harmonics. Although admiration and astonishment may be excited when one hears harmonics produced from the thaumaturgical fingers of a Kubelik, no one will deny that a long passage consisting of artificial and natural harmonics sounds very insipid and unsatisfactory. This bears out the statement made in PAR. 44 that harmonics (forming a composite clang) greatly enhance the beauty and quality of a fundamental; for if fundamentals could be freed from harmonics they would sound sweeter, perhaps, but thinner and more uninteresting.

HARMONICS AND FLUTES.

(*d*) Harmonics are often called flageolets[29] or flute notes, because they so nearly resemble the tones of the latter instrument. This is because flutes produce notes which are much simpler (that is to say, contain fewer harmonics) than other instruments.[30] Consequently, flute notes and harmonics are very much of the same character and quality. It is generally accepted that flutes are somewhat uninteresting instruments to listen to for long by themselves. They need the combination of some other instrument to counteract their simple sweetness.

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[29] Flageolets are wind instruments akin to the flute.

[30] Flutes only produce the octave-harmonic.

VARIETY OF TONE-COLOUR IN DIFFERENT INSTRUMENTS.

(*e*) All musical instruments, as well as the human voice,[31] pipes, bells, etc., produce harmonics (they can often be heard with remarkable distinctness in church bells, for instance), but they do not all produce the same number, or produce them in the same order.[32] It was discovered by Helmholtz that the distinctive difference in tone-colour between various instruments, by which one is able to distinguish, say, a violin from a clarinet, is due to this variety in their harmonics. Thus, violins, violoncellos, harps, etc., produce the same harmonics and have the same characteristic tone-colour (the resemblance between the harp and notes played *pizzicato* on the violin must be remembered). On the other hand, flutes, clarinets, oboes, etc., each produce different series of harmonics, and consequently have distinctive characteristics in their tone-colour. This similarity or difference is, of course, irrespective of size of instrument, mode of execution, variety of string material, etc.

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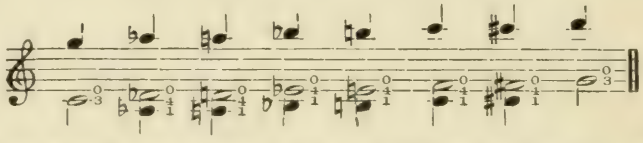
[31] As many as sixteen harmonics have been discovered in a bass voice. Soft, sweet voices produce fewer harmonics than those which are harsh and rough.

[32] A tuning-fork may be taken as the nearest approach to a pure, simple sound, practically free from harmonics.

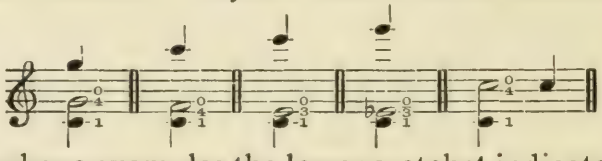
CHAPTER IX.—ARTIFICIAL HARMONICS.

114. If the previous chapters have been understood a very short explanation will suffice for the so-called "artificial" harmonics. The easiest of these, and the one most often used, is that of the "double-octave." It is obtained by simultaneously pressing the first finger *tightly* on the string, so as to produce a new fundamental, and lightly "damping" with the fourth finger at the distance of a *perfect fourth*. In this way the double-octave to any note from A flat below the lines to about A above the lines (or higher, according to the ability of the player) may be obtained, and a complete chromatic scale played in harmonics on the violin:—



The first and last harmonics in the above example are those of the *natural* "double-octaves" on the G and D strings.

115. Other artificial harmonics are obtained by varying the distance between the "stopped" and "damped" notes. Thus a perfect fifth between them produces the "octave-fifth" to the new fundamental; a major third between produces the "major-third"; a minor third between (very difficult to make "speak") produces the double-octave-fifth"; and an octave between (only possible in the lower positions by those with long stretching powers) produces the "octave." Beyond these it is not necessary to go:—



In all of the above examples the lower crotchet indicates the fundamental note to be pressed down, the minim the one to be "damped," and the upper crotchet the pitch of the harmonic produced.

116. The use of artificial harmonics may be said to date from Paganini (1782-1840), who employed them to a remarkable extent in his playing and compositions. Although they have hardly ever been introduced into purely classical works, they form an important part in the technical equipment of those who wish to become virtuoso players, or to be able to fully interpret the violin music of such composers as Paganini, De Beriot (1802-1870), Ernst (1814-1865), Vieuxtemps (1820-1881), Wieniawski (1835-1880), Sarasate (1844), etc. Spohr (1784-1859) denounced artificial harmonics in no measured terms, and spoke of them as "degrading a noble instrument." But perhaps one may venture to suggest that if Spohr had lived in the latter part of the nineteenth century he might possibly have modified his opinion.

CHAPTER X.—INTONATION AND RESULTANTS.

117. Before explaining Resultants it will be necessary to make a few observations on vibration and intonation.

118. It has been already stated (PAR. 10) that WHENEVER TWO SOUNDS FROM SIMILAR OR DIFFERENT SOURCES PERFECTLY AGREE IN PITCH, THE REASON FOR THIS AGREEMENT IS THAT THE VIBRATIONS WHICH CAUSE THE SOUNDS ARE EXACTLY EQUAL IN NUMBER ($\frac{1}{1}$), AND THE TWO SOUNDS WILL THEREFORE BE SAID TO BE IN UNISON. The vibrations of all intervals (as seconds, thirds, etc.) have specified ratios; those of the consonant intervals being as follow:—

Vibration Ratios of Consonant Intervals.

Perfect Unison	=	$\frac{1}{1}$	Perfect Octave	=	$\frac{2}{1}$
Perfect 5th	=	$\frac{3}{2}$	Perfect 4th	=	$\frac{4}{3}$
Major 3rd	=	$\frac{5}{4}$	Minor 3rd	=	$\frac{6}{5}$
Major 6th	=	$\frac{5}{3}$	Minor 6th	=	$\frac{8}{5}$

e.g., in the case of an octave the higher note gives *two vibrations* to each *one* of the lower note. Thus, if middle C vibrates 256 times per second, the upper octave will vibrate 512 times per second. In the major third the upper note will give *five vibrations* to every *four* of the lower note; and so on. Of the intervals given above the unison, octave, fifth, and fourth are, respectively, the most perfect and consonant *by reason of their vibrations most often coinciding.*

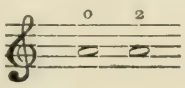
Beats.

119. When two sounds of the same pitch—producing the unison—are played *exactly in tune* on the violin, or when two or three strings are similarly tuned on the pianoforte, the combined sounds produce the effect of a *single note* with an increased tone as compared to that produced from one string. But when sounds or strings are a shade *out of tune* with one another, a peculiar trembling or puffing kind of sound is heard, known by the name of BEATS.

120. Beats can be very distinctly heard when playing on the violin in the following way:—

EXPERIMENT XXXI.

Play A on the D string (best with the second finger in the third position) together with the open A string—



so that the pitch agrees exactly. Now alter the fingered A so as to make it a shade flatter or sharper than the open A, and draw the bow very straight and with fair pressure on the strings. The trembling sound described above will be at once heard; slowly at first, but gradually faster the farther the finger is moved from its correct pitch. When the notes are the distance of a semitone apart the beats are too rapid to be disagreeably noticeable.

121. The reason for the above phenomenon is that beats are caused through the difference in vibration between the two notes occasioning them. Consequently just as many beats per second will be heard as there are vibrations more or less in one of the two notes. Thus, if open A vibrates 426 times and the A on the D string only, say, 420 times there will be six beats per second heard; and so on. Listening for beats is the principal guide to correct pianoforte tuning.

Just and Tempered Intonation.

122. If all intervals are tuned in what is known as *just* or *perfect intonation*, more than twelve notes are necessary for an octave, as a distinct, although very slight difference occurs between all enharmonic notes, such as B♯-C♮, F♯-G♭, etc. In keyboard instruments, such as the pianoforte, it is not practicable to employ more than twelve different pitches in an octave, therefore a method of tuning is adopted by which, whilst keeping all octaves in just intonation, other intervals are regulated or *tempered* so as to make *all enharmonics of identical pitch.* This is called *Tempered intonation.* Some such system dates from the time of Bach, who wrote his Forty-Eight Preludes and Fugues for the "well-tempered clavichord." Without pursuing this intricate subject farther, the following example may, perhaps, serve to make it clearer. The lowest C of a pianoforte has about thirty-two vibrations per second.[33] The seven successive octave C's will therefore have, respectively, 64, 128, 256, 512, 1,024, 2,048, and 4,096 vibrations per second, the last C corresponding to the highest note of a $7\frac{1}{4}$-octave pianoforte. If, however, twelve perfect fifths, covering exactly the same distance (C-G, G-D, D-A, A-E, E-B, B-F♯, F♯-C♯, C♯-G♯, G♯-D♯, D♯-A♯, A♯-E♯, E♯-B♯), are taken at the ratio of $\frac{3}{2}$ vibrations, the last and highest note—B♯—should have a fraction under 4,152 vibrations, or a difference of fifty-six vibrations between

[33] The usual pitch is slightly higher than this; but it is sufficiently near for the purpose, and, as stated in PAR. 14, this is the simplest figure from which to work the resultants.

the enharmonic B♯ and C♭.[34] This difference, in tempered intonation, would be adjusted or distributed throughout the twelve perfect fifths. The "tempering" begins with various fourths and fifths at the middle of the keyboard; then the octaves are tuned *perfectly* upwards to the highest notes and downwards to the lowest. So it comes that "tuning" a pianoforte means putting it slightly *out of tune*, as far as *just* intonation is concerned.

Resultants.

123. Resultants are tones which can be heard whenever two musical notes are sounded together, loudly and continuously. Giuseppe Tartini (1692-1770), the celebrated Italian violinist, and composer of the well-known sonata, "Il trillo del Diavolo," was probably the first to discover resultants, and made great use of them in teaching double-stopping on the violin; they have consequently often been called *Tartini's Tones*. Other names for them are *Differential* or *Combinational Tones*. They have lately been introduced in the *Technical Exercises* of "A Modern School for the Violin," by Messrs. Wilhelmj and Brown.

124. The first cause for the existence of resultants is as follows:—If the vibration number of the lower of two notes less than an octave apart is subtracted from that of the higher, the remainder will give the vibration number of a still deeper note, and it is this deeper note which will sound as a resultant. Hence the meanings of the various terms:—*Resultant*, the result of the blending together of two notes; *differential*, the difference in rate of vibration between two different sounds; *combinational*, a tone produced by the combination of two sounds.

125. It is a somewhat curious fact that many violinists will continue to play for years without noticing or hearing resultants; but the moment attention is drawn to their existence the ear is quickly attracted to them. It is a debatable question whether listening for resultants is a help or otherwise to the violin student; nevertheless, whenever the proper resultants are heard it is a sure sign that at least the two notes producing them are in good tune together.

126. For example, if in tuning together the A and E strings of a violin one clearly hears the lower A as a resultant, it is a guide that the two open strings are in good tune; similarly, one should hear the lower octave D when tuning the D and A strings, and the

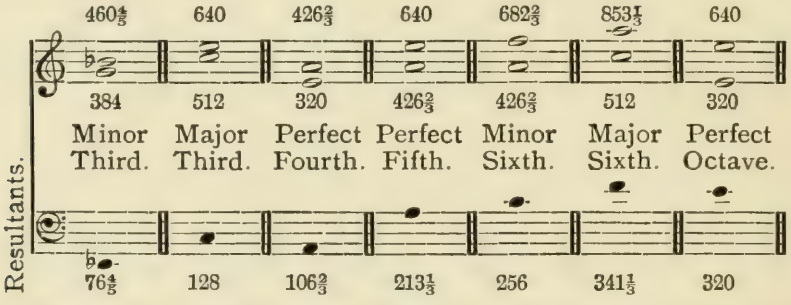
---

[34] The above example will explain the correct meaning of the term *enharmonics;* viz., intervals of less than a semitone. As enharmonic notes are all tuned alike on the pianoforte the only difference usually observable is a change of *notation;* but it will be perfectly apparent that in music for unaccompanied strings or voices it is quite possible to correctly observe enharmonic modulations and just intonation.

lower octave G when tuning G and D; but the very deep resultants are much more difficult, and often impossible to hear.

127. When beginning to listen for resultants, it will be as well to play at first the open A and E strings, loudly and with a well-sustained tone. The resultant will be A below the lines; for taking the vibration number of open A at $426\frac{2}{3}$, that of the open E will be 640, as 640 is $\frac{3}{2}$ of $426\frac{2}{3}$; now subtract the lower from the higher number and it leaves $213\frac{1}{3}$, which will be the vibration number of the lower octave A.

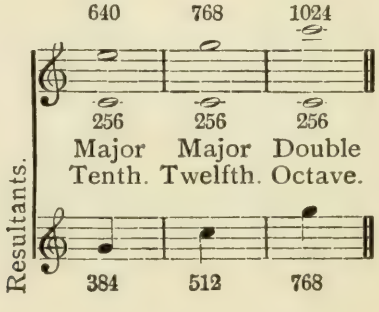
128. The following table shows the resultants to all the simple consonant intervals. The vibration numbers are given to each note, and double notes have been chosen which are easy to play on the violin :—



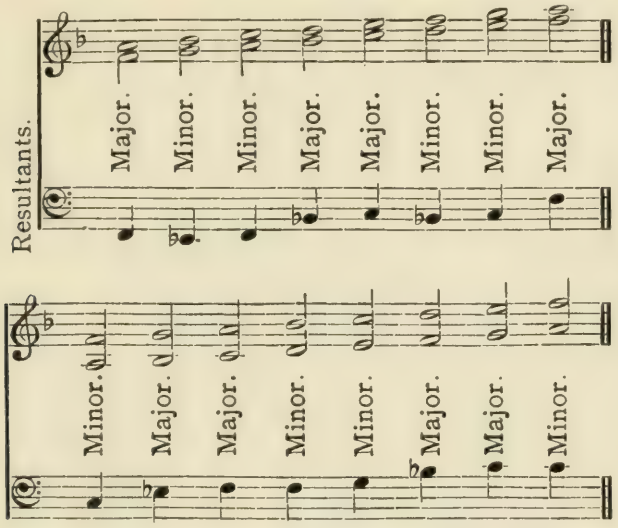
129. From the foregoing the following general deduction may be made :—

Interval.		Resultant.	
An Octave	produces a note	the same as	the lower of the two notes forming the interval.
A Major Sixth		perfect fifth deeper than	
A Minor Sixth		major sixth ,,	
A Perfect Fifth		an octave ,,	
A Perfect Fourth		an octave and perfect fifth deeper than	
A Major Third		two octaves deeper than	
A Minor Third		two octaves and a major third deeper than	

130. It will be noticed that *inside* an octave the *smaller* the interval is the *deeper* will be the resultant. *Beyond* an octave the resultant lies *between* the two notes of the interval; for example :—



131. In scales of thirds and sixths the resultants come out very clearly. They will be distinctly heard, too, if the thirds and sixths are taken as single notes on two violins, provided the players stand near each other. They are heard best in an empty room. The following examples may be of service:—



132. Students who wish to further pursue the subject of sound in any of its bearings are referred to the list of works mentioned in the beginning.

THE END.

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Ditto ditto (Sol-fa)	0	9
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Ditto ditto (Sol-fa)	0	8

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